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(71) Applicant(s)
Institut Francais du Petrole

(Incorporated in France)

4 Avenue de Bois-Preau, 92502 Rueil-Malmaison, France

(72) Inventor(s)
Didier Pavone
Christophe Vignat
David Brunet

(74) Agent and/or Address for Service
Fitzpatricks
Cardinal Court, 23 Thomas More Street, LONDON, E1 9YY, United Kingdom

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(54) **Determining slip-stick type dysfunction during drilling**

(57) Torsional oscillations of a drill string which is rotated from the surface are determined in real time, and damping associated with at least one natural low frequency of the oscillations is determined in real time. The appearance of a dysfunction of the stick-slip type is predicted as soon as the value of damping decreases significantly. The drilling parameters are then modified in order to prevent the occurrence of this dysfunction.

FIG.1

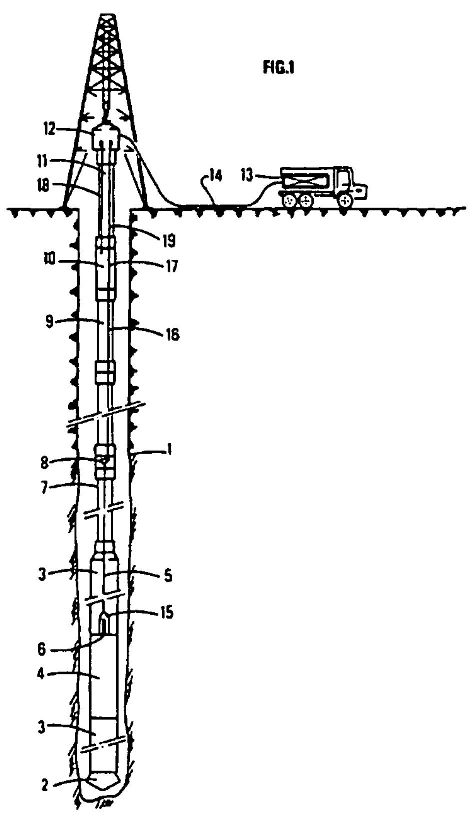

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FIG.1

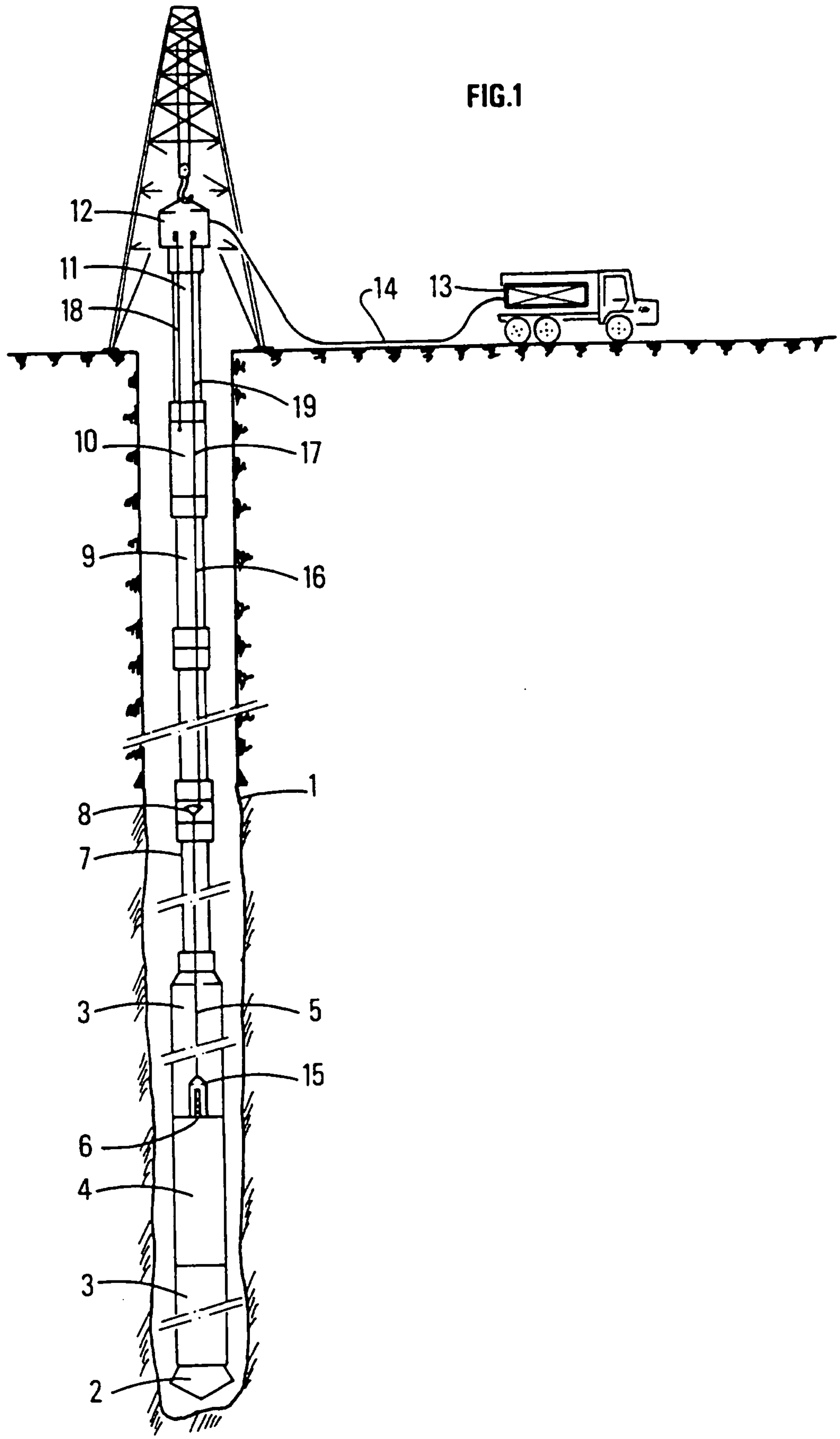
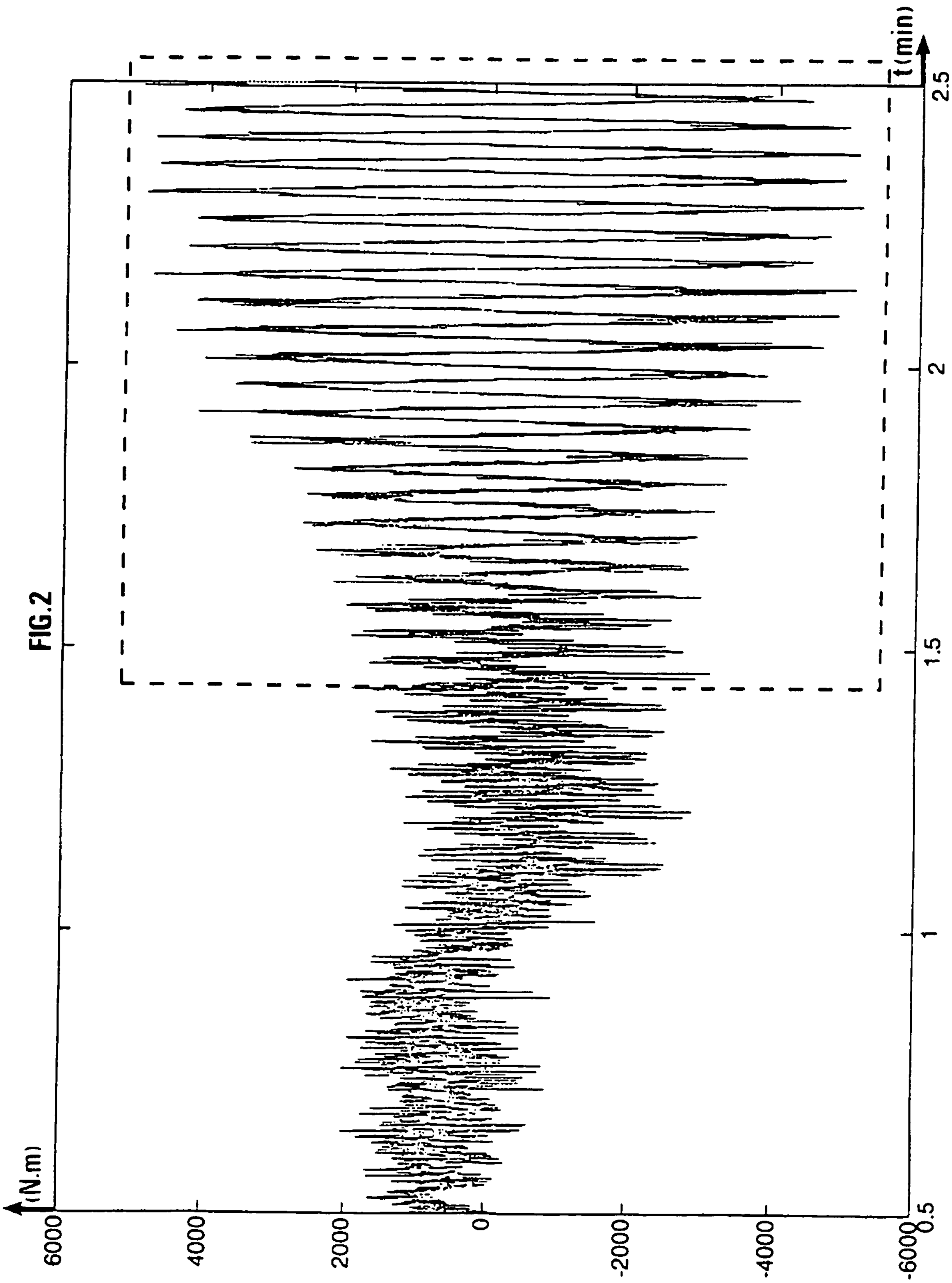


FIG.2



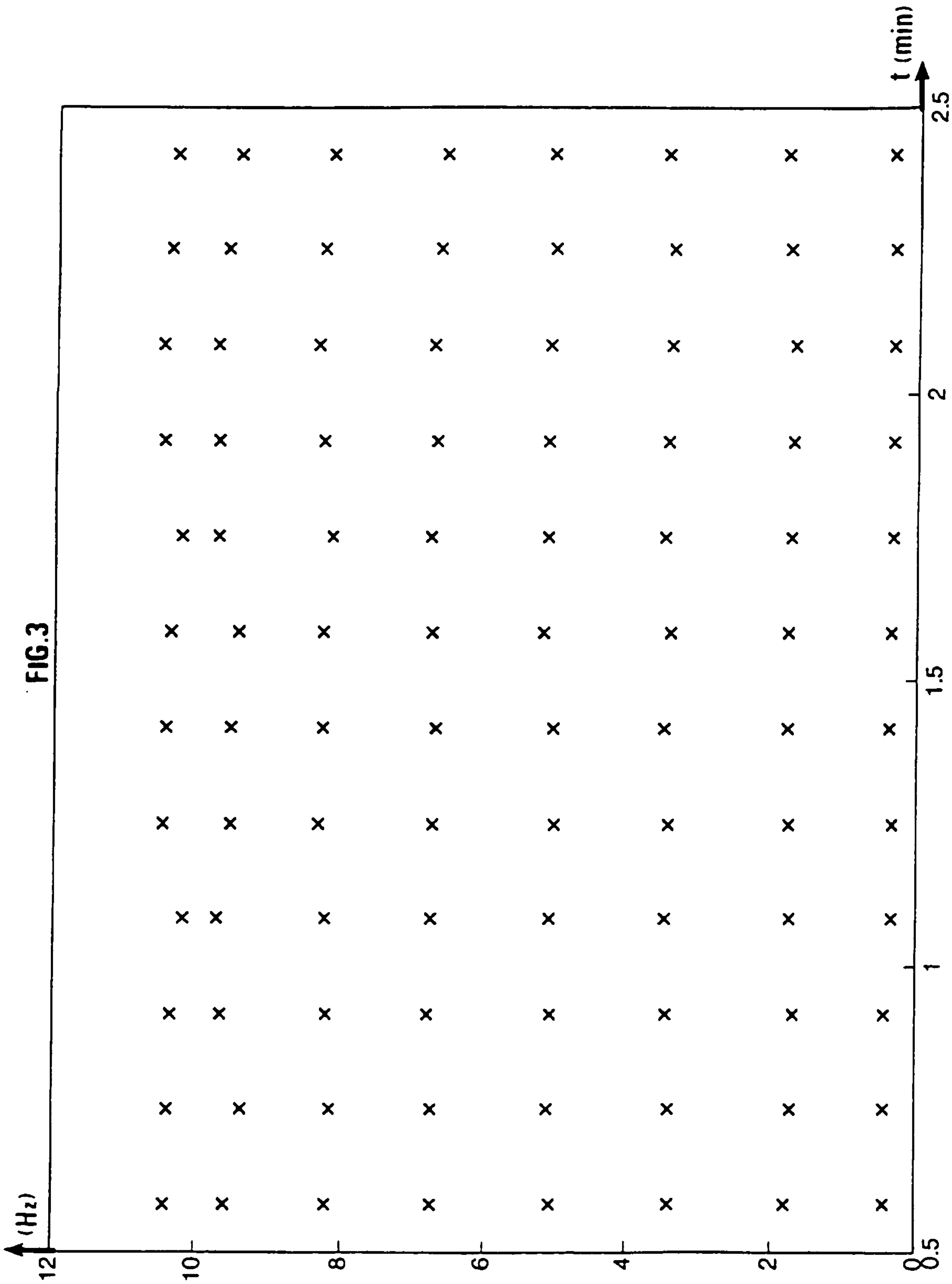
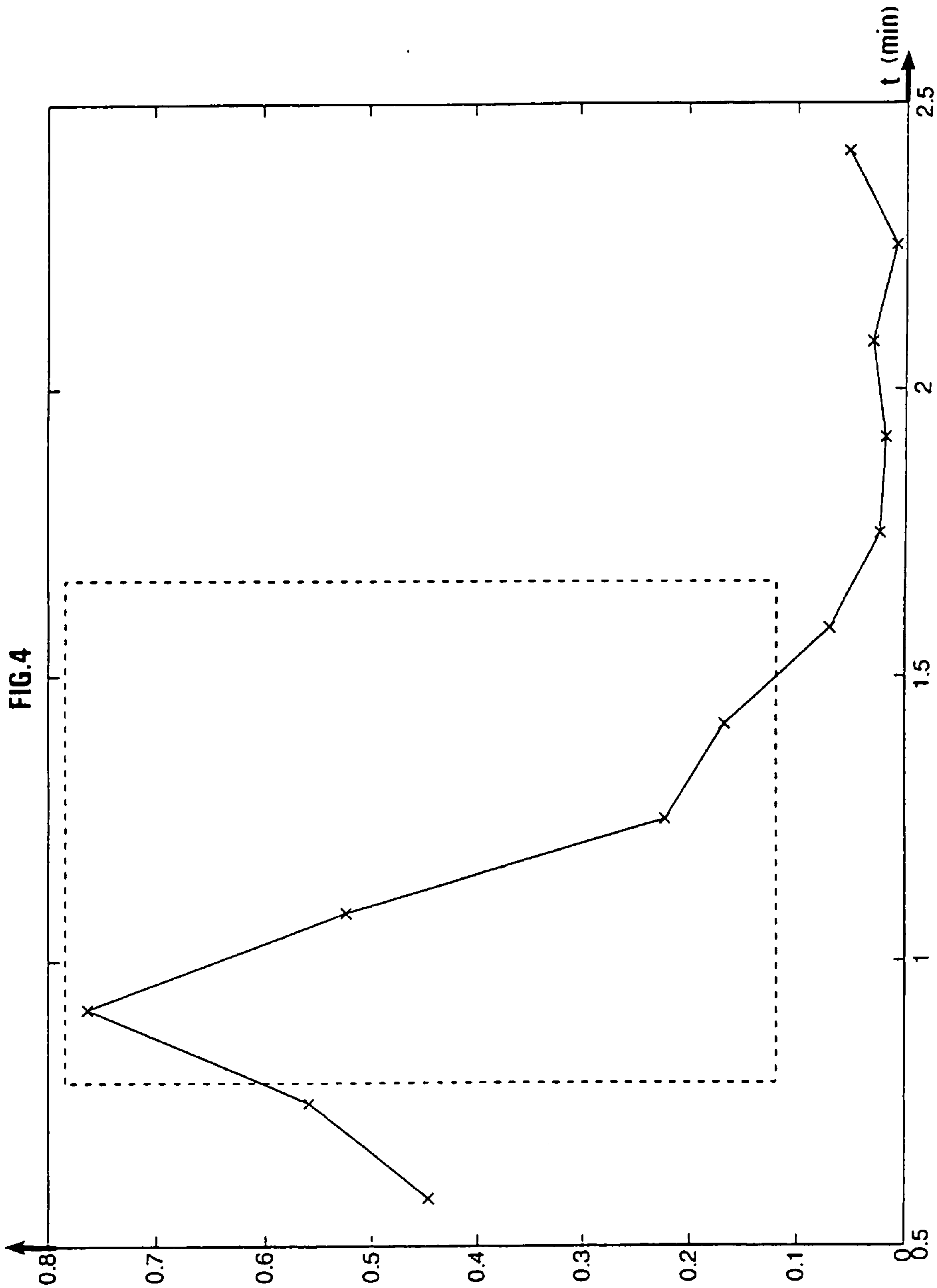


FIG.3

FIG.4



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The present invention relates to a method and a system designed to monitor a dysfunction in the behaviour of a drilling tool rotated by means of a drill string. This dysfunction is commonly known as "stick-slip". In particular, the present invention provides means allowing the occurrence of the dysfunction to be predicted so that the various drilling parameters can be modified in order to prevent stick-slip from actually occurring.

Stick-slip behaviour is well known to drilling personnel and is characterised by very sensitive variations in the rotation speed of the drill bit as it is rotated from the surface by a drill string at an essentially constant speed. The speed of the bit may vary between a value that is practically zero and a value greatly in excess of the rotation speed applied to the string at the surface. This can be detrimental to the useful life of drill bits in particular and increase the mechanical fatigue of the drill string and the frequency at which the connections break.

From the article "Detection and monitoring of the stick-slip motion: field experiments" by M.P. Dufeyte and H. Henneuse (SPE/IADC 21945 - Drilling Conference, Amsterdam, 11-14 March 1991), the idea of analyzing stick-slip behaviour using measurements taken by a device placed at the upper end of the drill string is known. In the event of a stick-slip dysfunction, this document recommends either increasing the rotation speed of the drill string from the rotary table or reducing the weight on the tool by means of the drilling winch.

The article "A study of slip-stick motion of the bit" by Kyllingstad A. and Halsey G.W. (SPE 16659, 62nd Annual Technical Conference and Exhibition, Dallas, September 27-30, 1987) analyses the behaviour of a drill bit using a pendular model.

The article "The Genesis of Bit-Induced Torsional

Drillstring Vibrations" by J.F. Brett (SPE/IADC 21943 - Drilling Conference, Amsterdam, 11-14 March 1991) also describes the torsional vibrations caused by a PDC type bit.

However, although various methods have already been formulated within the profession for trying to halt the stick-slip phenomenon, no solution has been produced that will predict and prevent the occurrence of the phenomenon.

The present invention therefore relates to a method of optimising drilling by allowing the stick-slip dysfunction to be predicted, in which the drilling means consist of a bit fixed to the lower end of a drill string rotated from the surface and at least one device having means for measuring the torsional oscillations of the drill string in real time. In this method, the damping associated with at least one natural low-frequency mode of the said oscillations is identified as a function of time and at least one drilling parameter is modified as soon as a significant decrease in the value of the said damping occurs.

A function of linear transfer between the downhole torsion signals and the surface torsion signals can be determined and the damping associated with the lower frequency natural modes can be calculated.

The damping associated with a pole of the transfer function can be calculated from the following formula:

$$\mu = \mathrm{Log}(1/P)/[m^2+\mathrm{Log}^2(1/P)]^{1/2}$$

where P is the modulus of the pole and m the phase of the pole.

The downhole and surface torque signals can be measured in real time and a transfer function corresponding to an auto-regressive moving average (ARMA) model can be determined in real time.

The invention also relates to a system of optimising drilling allowing a dysfunction of the stick-slip type to

be predicted, in which the drilling means consist of a bit fixed to the lower end of a drill string rotated from the surface and at least one device with means for measuring the torsional oscillations of the drill string in real time. The system has means for calculating the damping associated with at least one natural low frequency mode of the said oscillations as a function of time and means for monitoring the occurrence of a significant decrease in the value of the said damping.

The system may have means for measuring downhole and surface oscillations relative to the drill string and means for determining a function of transfer between the bottom hole and the surface.

The invention will be more readily understood and its advantages clearer from the following description of examples, which are not limitative in any respect, illustrated by the attached drawings, in which:

- Figure 1 illustrates a system allowing the invention to be implemented.

- Figure 2 shows a surface recording of a torque signal as a function of time.

- Figure 3 shows the frequency calculations of the natural modes of the torque signal over the same period of time.

- Figure 4 shows changes over the same period of time in the damping coefficient associated with the first natural mode (in this instance 0.3 Hz) when the stick-slip dysfunction occurs.

In figure 1, reference 2 denotes the drill bit, lowered into the well 1 by means of the drill string. Conventional drill collars 3 are screwed in above the tool. A first measuring means consists of a sub 4, generally placed above the bit 2 where the measurements close to the tool are of the greatest interest, particularly in terms of monitoring the dynamics of the

bit. However, it could be located inside or at the top of the drill collars or even at the level of the drill pipes.

The remainder of the drill string is made up of conventional pipes 7 up to the suspension and connector sub 8. The drill pipes are extended above this sub by means of cabled pipes 9.

The cabled pipes 9 are not described in this document since they are known from the prior art, in particular from patents FR-2530876, US-4806115 or application FR-2656747.

A second measuring means placed in a sub 10 is screwed underneath the drive rod or kelly 11, the cabled pipes being added underneath this sub 10. Above the kelly 11 is a rotating electrical connector 12, which is electrically connected to the surface installation 13 by means of a cable 14.

If the drilling equipment is fitted with a motorised injection head, commonly known as a power swivel, no kelly is needed and the measuring sub 10 is screwed directly underneath the rotating connector 12 located below the power swivel.

The measuring sub 4 has a male connector 6, the contacts of which are linked to the measuring sensors and the relevant electronic circuitry incorporated in the sub 4.

A cable 5, equivalent to a wireline logging cable, has at its lower end a female connector 15 designed to co-operate with the connector 6. The other upper end of the cable 5 is suspended on the connector 8. The connector 8 is designed to suspend the cable length 5 and electrically link the conductor(s) of the cable 5 to the power line(s) of the cabled pipe immediately above. The electrical link provided by the cabled pipes is denoted by reference 16. This electrical link passes through 17 into the second measuring sub 10.

If a kelly 11 is used, this is also cabled and incorporates two electric cables 18 and 19. One, 18, links the second sub 10 to the rotating contacts of the rotating connector 12 and the other, 19, links the line 17 to the other rotating contacts of the connector 12.

The surface cable 14 may have at least six conductors.

The sub 4 is generally linked by a single-core cable to the surface installation 13. The measurements and power supply pass along the same line.

The measuring means of the sub 4 preferably has sensors for measuring individually or in combination:

- the weight on the bit,
- the reactive torque around the drill bit,
- the bending moments along two orthogonal planes,
- the accelerations along three orthogonal axes, one of which coincides with the longitudinal axis of the drill string,
- the temperatures and pressures inside and outside the drill string,
- the rotation acceleration,
- the components of the magnetic field.

The first three measurements can be obtained by strain gauges bonded onto a test cylinder. An appropriate housing protects them from the pressure. This housing is designed and mounted essentially so as to avoid any measuring errors due to outputs.

The accelerations are measured using two accelerometers per axis in order to monitor any errors caused by the rotation dynamics.

The final set of measurements is obtained by specific sensors mounted in a separated part of the sub.

The mechanical specifications of the first sub 4 are, for example:

- external diameter: 20.3 cm (8 to 8.25 inches),

- length: 9 m,
- tensile/compressive strength: 150 tf,
- torsional strength: 4,000 m.daN,
- bending strength: 7,500 m.daN,
- internal and external pressure: 75 MPa,
- temperature: 80°C.

The second measuring means of the measuring sub 10 preferably has, singly or in combination, sensors for measuring:

- tension,
- torsion,
- axial acceleration,
- internal pressure or delivery pressure at the pumps,
- rotation acceleration.

The design of this surface sub 10 is basically no different from that of the first sub except that it is necessary to leave a passageway free for mud, arranged substantially coaxially with the interior space of the drill string to allow a bit to be moved inside the drill string if necessary.

The mechanical specifications of the second sub 10 are, for example;

- external diameter: 20.3 cm (8 to 8.25 inches),
- length: 1.5 m (5 feet),
- tensile strength: 350 tf,
- torsional strength: 7000 m.daN,
- internal/external pressure: 75/50 MPa.

In a variant of the acquisition system of the embodiment illustrated in figure 1, the measurements can be transmitted at high frequency by means of the power lines provided by the cable 5, lines 16 and 17 and the surface cable 14.

An acquisition system of this type is described in document FR-2688026.

Figure 2 shows a torque signal recorded by the surface sub 10. The recording duration is two minutes, from 0.5 to 2.5 min in the abscissa. The amplitude of the oscillations, in the ordinate, is expressed in N.m. The portion of the signal illustrated consists of a zone of strong oscillations starting from 1.5 in the zone of the abscissa corresponding to a stick-slip dysfunction. The preceding zone is a zone of normal operation.

The objective of the invention is to calculate the damping coefficient associated with the first natural mode relative to the stick-slip. To this end, a function of transfer between the downhill signals and the surface signals is identified, such as the downhole torque measured by the downhole sub 4 and the surface torque measured by the surface sub 10.

It is here that the auto-regressive moving average (ARMA) models, which are well known, are used and these can be characterised by the following equations:

$$x(t) = \sum_{k=1}^{p} a_k \,.x(t-kT) + \sum_{k=0}^{q} b_k \,.u(t-kT-nT) + e(t)$$

where x(t) is the output signal, u(t) the input signal and e(t) a white noise.

Auto-regressive models are described in the following works:

- "System Identification Toolbox User's Guide", July 1991, The MathWorks, Inc - Cochituate Place, 24 Prime Park Way, Natick, Mass. 01760.

- "System Identification - Theory for the User" by Lennart LJUNG, Prentice-Hall, Eaglewood Cliffs, N.J., 1987.

- "Digital Spectral Analysis with Applications" by S. Lawrence MARPLE Jr., Prentice-Hall, Eaglewood Cliffs,

N.J., 1987.

- "Digital Signal Processing" by R.A. ROBERTS and C.T. MULLIS, Addison-Wosley Publishing Company, 1987.

When identifying an auto-regressive model, the most delicate stage is determining its orders (p, q), i.e. the number of coefficients of the model. In practice, if the order selected is too low, the model will not be able to represent all the vibration modes. Conversely, if the order of the model selected is too high, the transfer function obtained will have more natural modes than the system and may therefore lead to errors. The implications of a modelling error can be significant.

The delay nT represents the transfer time of a signal through the drill string. The transmission speed of the shear waves is about 3,000m/s. Therefore, if the length of the drill string during recording is known, it is possible to determine the delay nT automatically. For example, when the signal illustrated in figure 2 was acquired, the length of the drill string was about 1,030 m, which gives a delay nT of 0.34 s, which is approximately n=15 values for a data sampling at 45 Hz.

Determining p: Tests were carried out in order to determine the parameter p representing the number of poles of the transfer function. In order to gain a preliminary notion of the value of p, a spectral study of the signals was carried out to determine the number of frequency peaks with phase change, which is associated with the number of natural modes. This gave an idea of the order of magnitude of p, since it is known that two conjugate complex poles correspond to each natural mode and p is therefore equal to twice the number of natural modes. At the end of this first approximation, the value of p is within the range between 24 and 36.

After carrying out a series of tests on different torque signals, the optimal determination of p is 26.

The parameter q is determined by incrementing from the starting value 1 until an optimal representative model is obtained. The real surface signals were therefore compared with those obtained using the function transfer based on the downhole signals recorded by the downhole sub 5. The equation q = 1 proved to be sufficient.

In the case of auto-regressive models, the polynomial

$$A(z) = 1 + \sum_{k=1}^{p} a_k \cdot z^{-k}$$

constitutes the denominator of the transfer function obtained. Consequently, if the zeros of this polynomial are determined, the poles of the transfer function associated with the natural modes of the system will be obtained.

Figure 3 shows the changes in the natural modes of the signal of figure 2 as a function of time in the abscissa and the frequencies in Hertz in the ordinate. The natural modes here are calculated on the basis of the principle described above. The stability of the natural modes as shown by a cross clearly show the existence of an unvarying function of linear transfer between the bottom hole and the surface with respect to the twisting moment.

The following formula was used to calculate the dampings μ associated with the natural modes:

$$\mu = \mathrm{Log}(1/P)/[m^2+\mathrm{Log}^2(1/P)]^{1/2}$$

where P is the modulus of the pole and m the phase of the pole corresponding to the natural mode.

Figure 4 shows changes as a function of time in the damping of the first mode, i.e. 0.3 Hz, which is associated with the stick-slip dysfunction which causes strong oscillations of the torque with effect from the time 1.5 on figure 2. At the time 1.5, therefore, it can

be seen that the damping underwent a sharp decrease which correlatively generated the stick-slip.

It is therefore possible to predict the start of the stick-slip by calculating in real time the damping value of the natural mode associated with the stick-slip. In our example, the first natural mode has been used but clearly in other examples relating to another system this could also be a mode other than the first mode, for example the second or even the third mode. However, in experimental terms, it is recognised that only the first natural modes can be associated with the stick-slip dysfunction.

A system enabling damping in real time to be calculated on the basis of torque signals at the surface and possibly downhole torque signals makes it possible to predict the start of stick-slip by analyzing changes in the damping value in real time. The means used to calculate and determine a transfer function are preferably installed at the surface 13 (figure 1). When damping reaches a low value within the space of several tens of seconds, the operator can be alerted by an alarm and then correct the drilling parameters in order to prevent the stick-slip. The drilling parameters may be the weight on the tool, the rotation speed or the friction torque on the walls of the well if a remotely-controlled device is incorporated in the drill string.

CLAIMS

1. A method of optimising drilling enabling a dysfunction of the stick-slip type to be determined, in which drilling means consist of a bit fixed to the lower end of a drill string rotated from the surface and at least one device with means for measuring the torsional oscillations of the said string in real time, wherein the damping associated with at least one natural low frequency mode of the said oscillations is determined in real time and at least one drilling parameter is adjusted as soon as a significant decrease arises in the value of the said damping.

2. A method as claimed in claim 1, wherein a function of linear transfer between the downhole torsion signals and the surface torsion signals is determined and the damping associated with the natural modes of lower frequency is calculated.

3. A method as claimed in claim 1, wherein the damping associated with a pole of the transfer function is calculated on the basis of the following formula:

$$\mu = \mathrm{Log}(1/P)/[m^2+\mathrm{Log}^2(1/P)]^{1/2}$$

where P is the modulus of the pole and m the phase of the pole.

4. A method as claimed in one of the previous claims, wherein the downhole and surface torsion signals are measured in real time and a transfer function corresponding to an auto-regressive moving average (ARMA) model is determined in real time.

5. A system of optimising drilling allowing a dysfunction of the stick-slip type to be predicted, in

which drilling means consist of a bit fixed to the lower end of a drill string rotated from the surface and at least one device with means for measuring torsional oscillations of the drill string in real time, characterised in that it has means for calculating as a function of time the damping associated with at least one low frequency natural mode of the said oscillations and means for monitoring the occurrence of a significant decrease in the value of the said damping.

6. A system as claimed in claim 5, wherein it has means for measuring the downhole and surface torsional oscillations relative to the drill string and means for determining a function of transfer between the bottom hole and the surface.

7. A method substantially as hereinbefore described with reference to the drawings.

8. A system substantially as hereinbefore described with reference to the drawings.

The Patent Office

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Application No: GB 9605347.5
Claims searched: 1-8

Examiner: David Mobbs
Date of search: 11 June 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1G GPU; G3N NGA9, NGBB3, NGBE2.

Int Cl (Ed.6): E21B 44/00.

Other: ONLINE: WPI.

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	WO 94/19579 A1 BAKER HUGHES INCORPORATED.	
A	WO 92/05337 A1 SOCIETE NATIONAL ELF AQUITAINE (PRODUCTION).	
A	US 4,250,758 TEXACO INC.	

X Document indicating lack of novelty or inventive step	A Document indicating technological background and/or state of the art.
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